Identifying High Burnup LOCA Test Conditions to Support LOCA Testing

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Overview/Objective

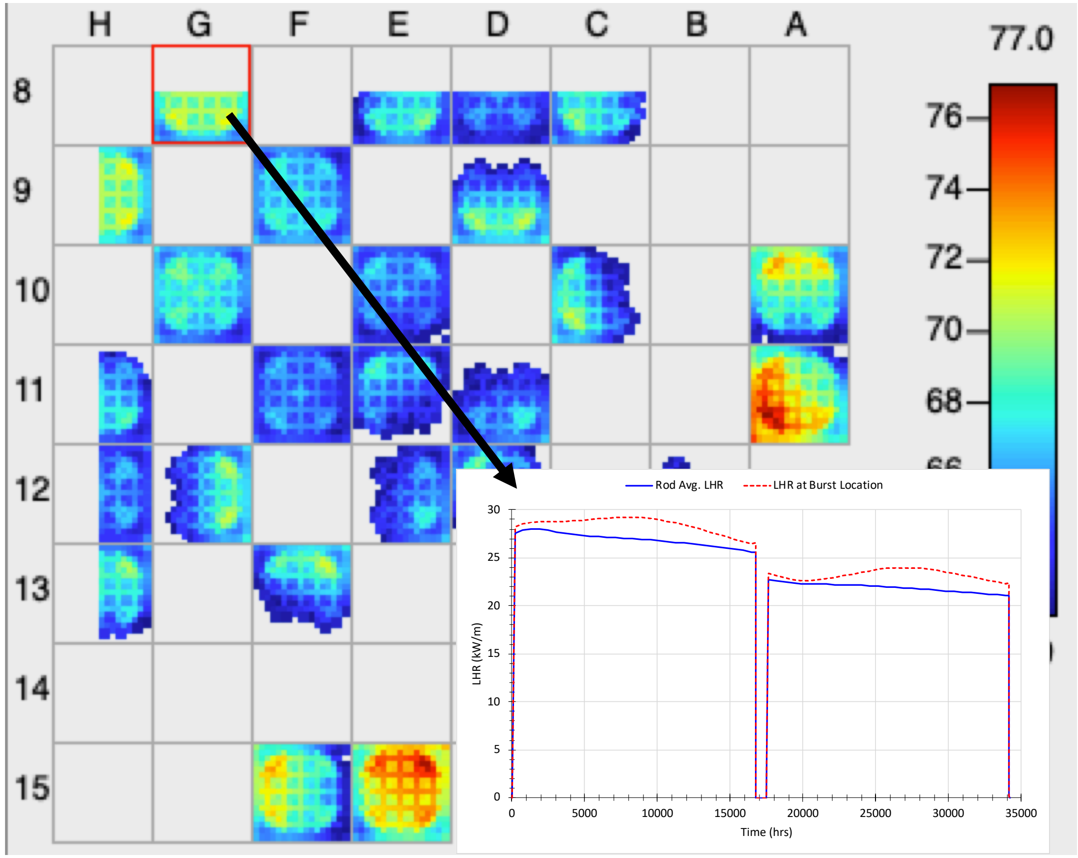
- Objective
  - Investigate high burnup fuel operating conditions (steady state and transient) to support development of ”realistic” LOCA test conditions for TREAT and SATS testing
  - Understand the differences between best estimate HBu and hot rod (i.e. peak temperature) LOCA scenarios for relevant HBu cores
  - Use DOE tools to evaluate those scenarios for TREAT and SATS LOCA test of a commercial fuel rod

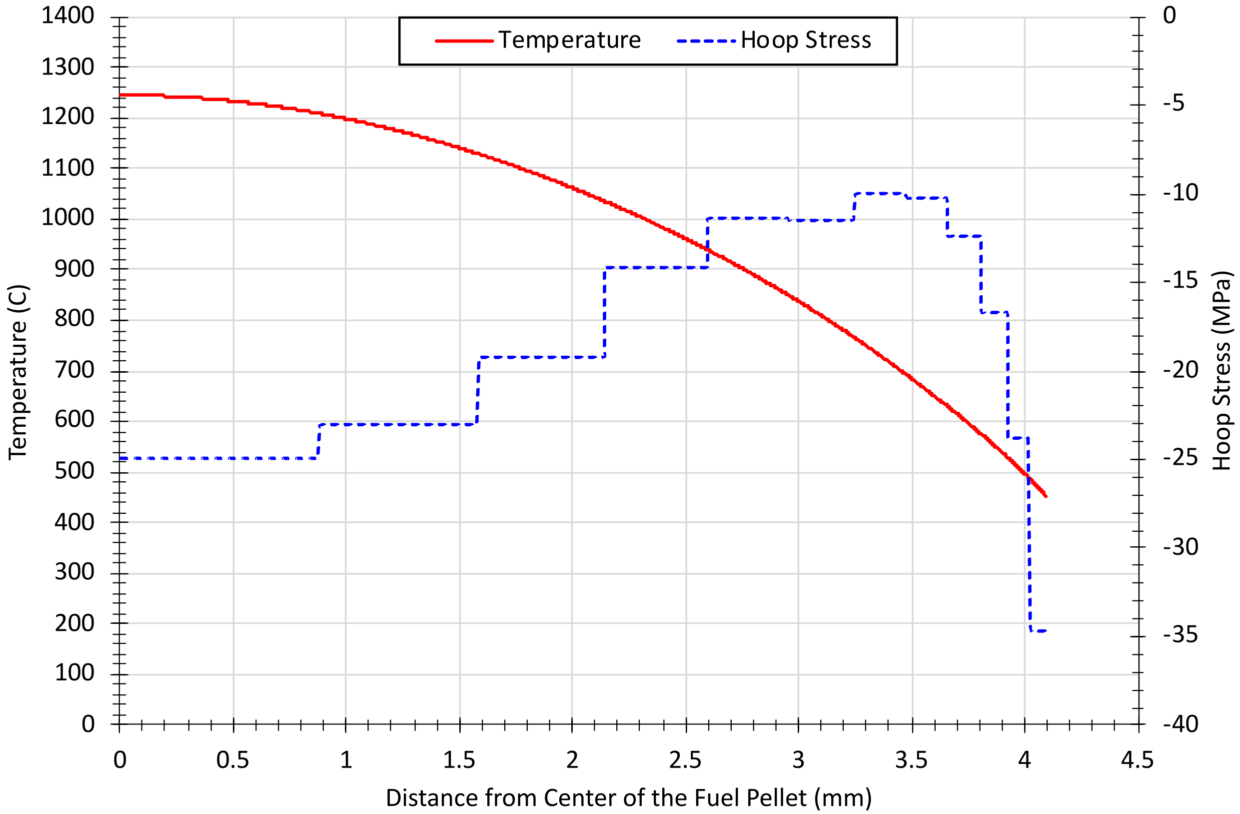
- Successful Outcome
  - Identify fuel rod steady state and transient conditions to support Fuel Fragmentation, Relocation, and Dispersal (FFRD) experimental test matrix development
  - Identify analytical differences or lack of differences between between nuclear and electrical heating LOCA test rig experiments
  - Submit results for journal publication

- Long Term Objective: Enhanced connectivity between experimental design and execution to code validation and prediction

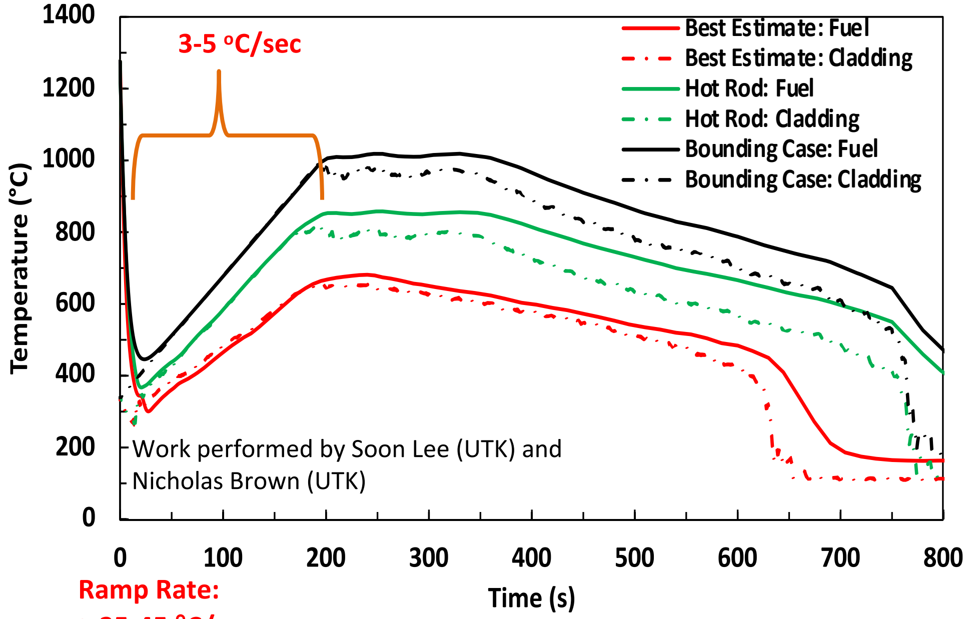
High Burnup Full Core LOCA Analysis: Steady State

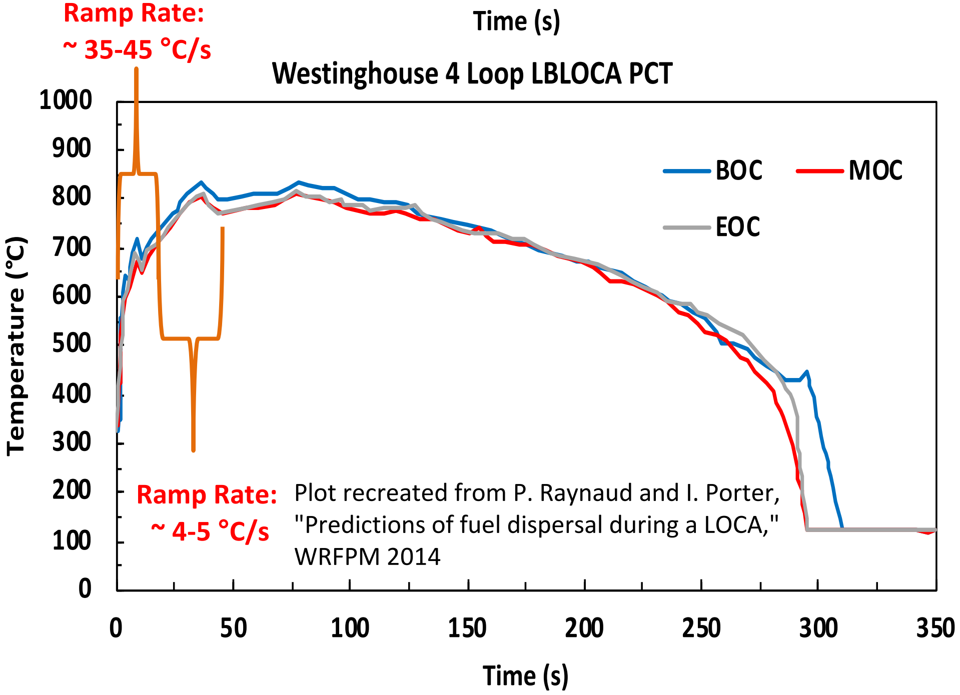
- Pin with the highest rod average burnup (~71.6 GWd/MTU) in the central regions of the core
  - Peak pellet burnup ~76 GWd/tU
- End of Cycle operating conditions
  - ALHR ~21 kW/m and LHR at burst location ~22 kW/m
    - Pellet burnup at burst location ~72 GWd/tU
  - Pre-transient fuel stress state in equilibrium



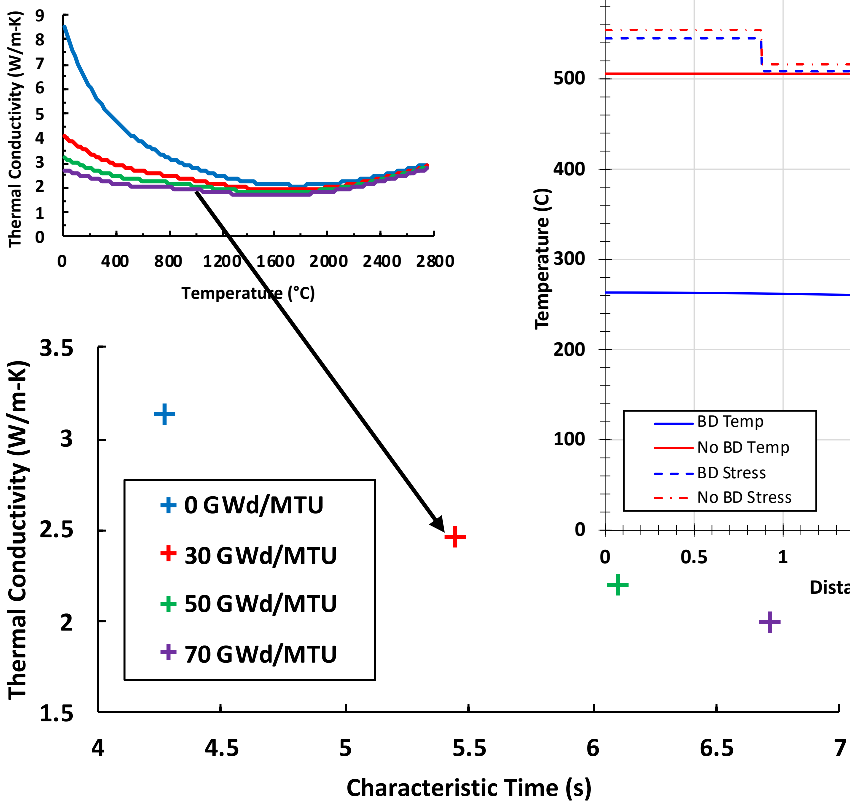


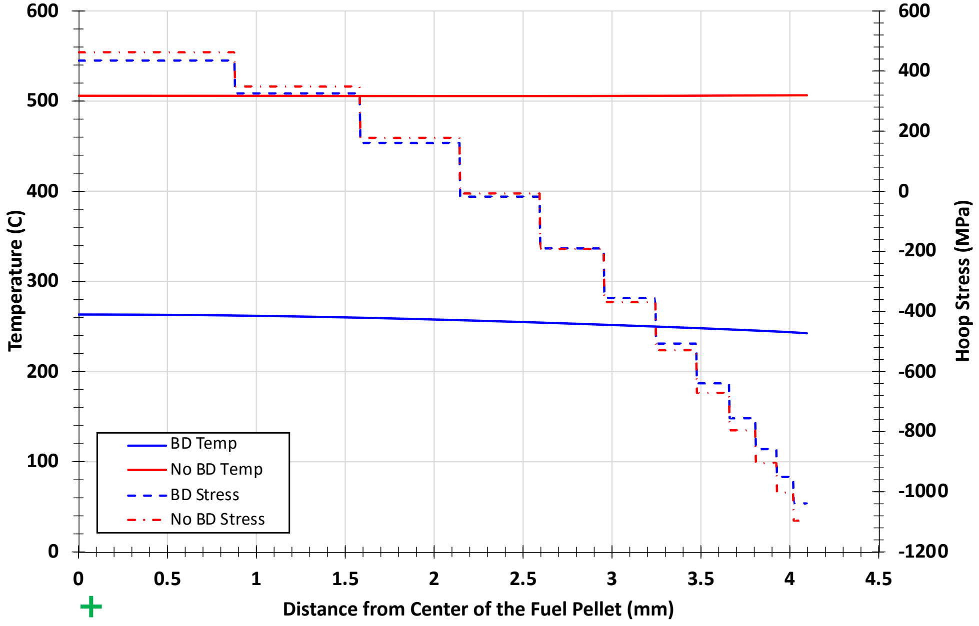
High Burnup Full Core LOCA Analysis: Transient



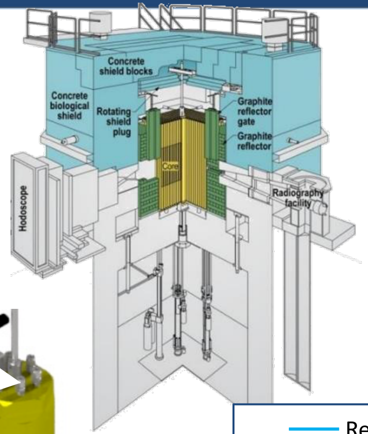


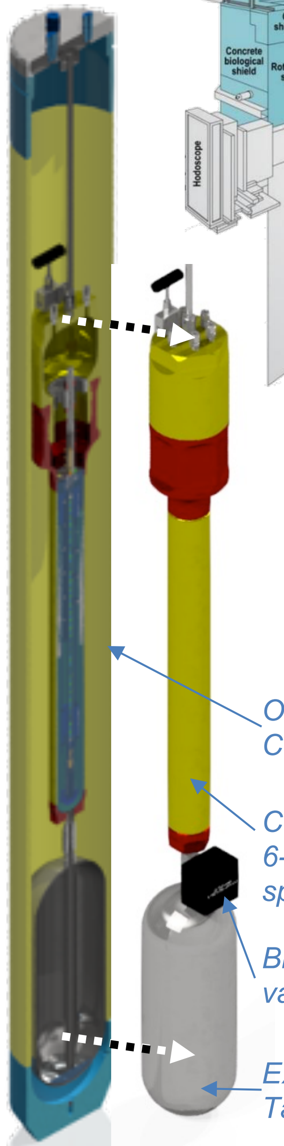
- Identified two cases:
  - High burnup analysis from a realistic high burnup core
  - Generic 4-loop Westinghouse PWR hot rod case
- Evaluated fuel conditions during the transients
  - Fuel thermal time constant 5-7 s
  - Removing the temperature gradient generates fuel stresses





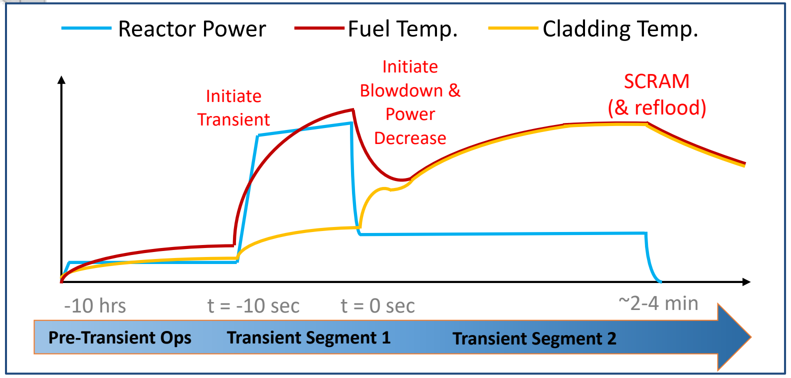
TREAT and SATS LOCA Testing Capabilities





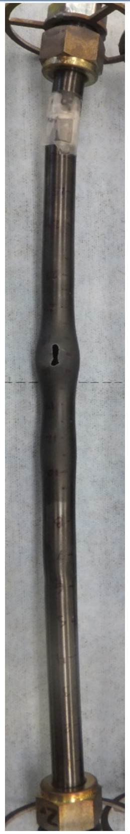
TWIST Capsule

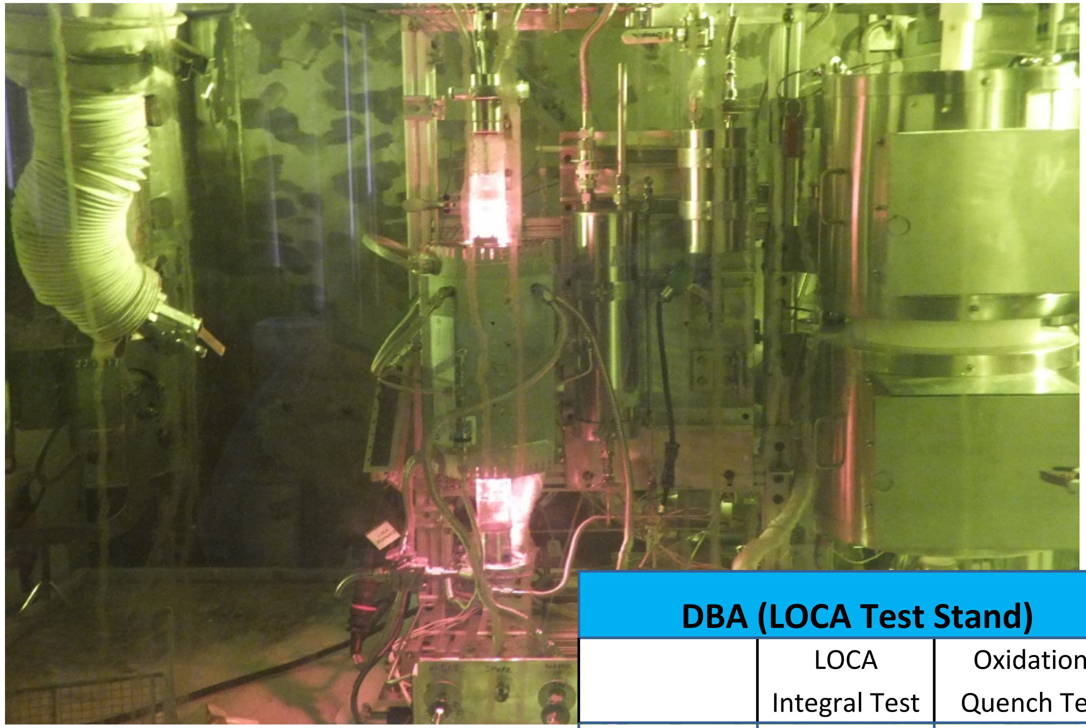
- Designed to provide fuel + cladding temperature control through duration of transient
  - 100% nuclear heating in specimen
  - Peak temperatures ~ > cladding melting
  - Heating rate > 2 °C/s
  - No recirculation in capsule
  - Recirculation possible in future loop device



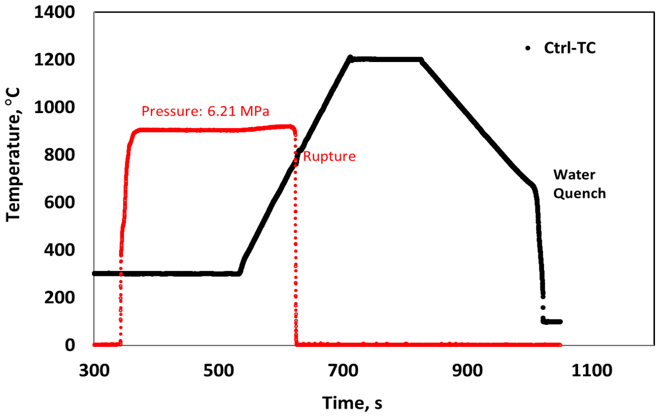
TREAT LOCA sequence

- Unique real-time diagnostics
  - **Fuel motion monitoring system**
  - **Cladding balloon extent**
  - **Non-contact balloon temperature measurement**
  - Fuel centerline temperature
  - Rod plenum pressure (fission gas release)
  - Cladding thermocouples
  - And more…





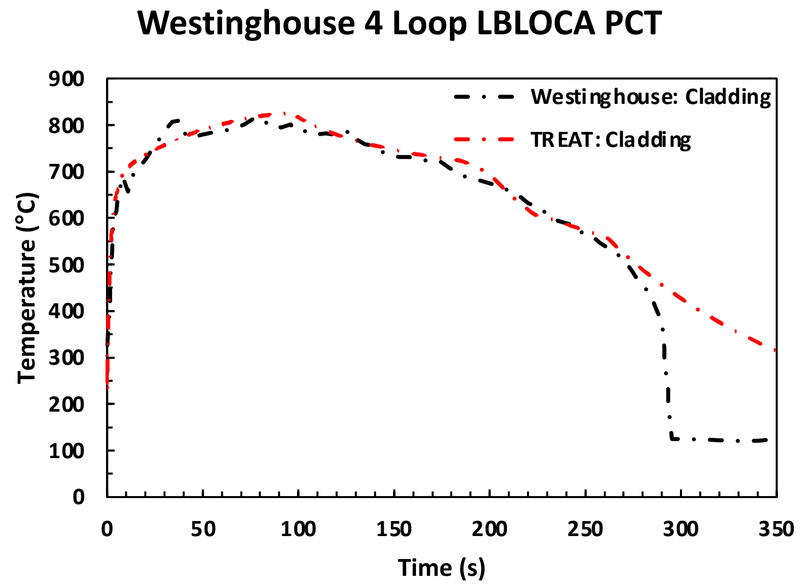
In-cell LOCA Test Zr-26 with Zircaloy-4, 8/7/2017

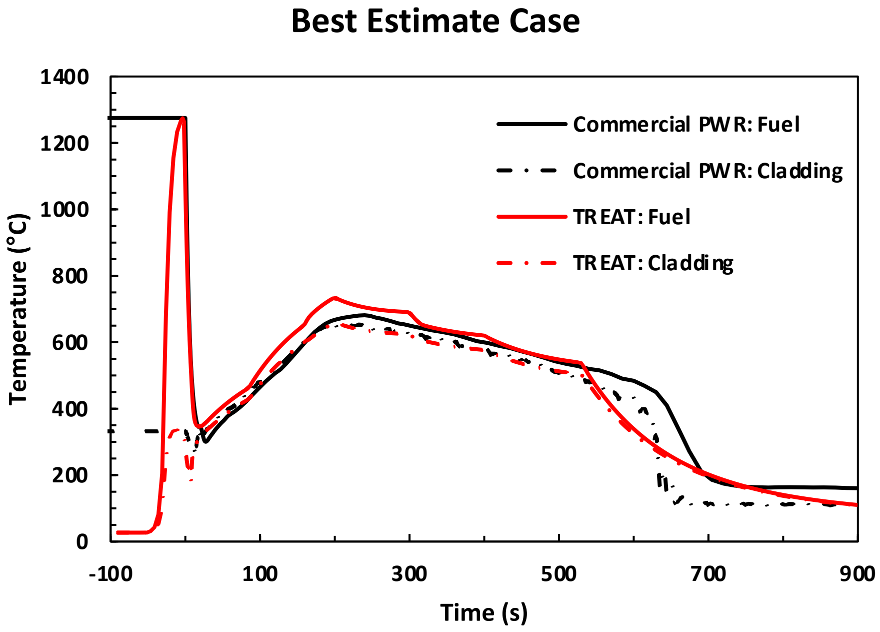


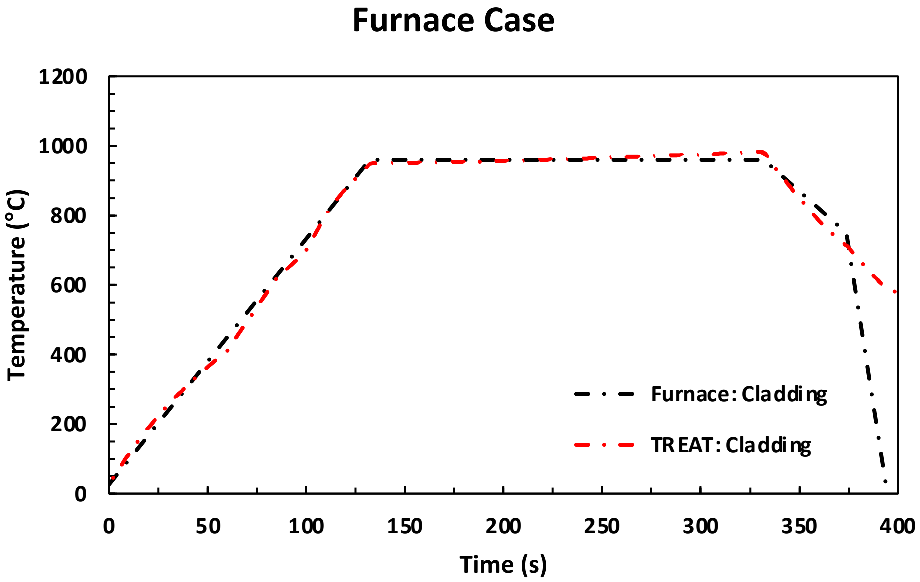
DBA (LOCA Test Stand)		
	LOCA Integral Test	Oxidation-Quench Test
Sample Spec	Fueled Rod	Defueled Clad
Segment (mm)	~200-300	~25-50
Pressure (MPa)	≈8, max 20	.1
Max Temp (°C)	1200	1200
Heating Rate (ºC/s)	5; max 20	5; max 20
Steam Flow Rate (mg/cm2·s)	~5.7	~5.7
Gas Environment	Steam or argon	Steam or argon
Quench (°C)	@ 20-800	@ 20-800

TREAT Test Rig Comparison to LOCA Transient Conditions

- TREAT vehicle flexibility allows for variety of conditions
  - Fuel starting conditions – Initial Power
  - Clad temperature ramp rate – “Decay” Power
  - Depressurization time – Blowdown Valve Opening Speed
  - TREAT and SATS can provide similar conditions to allow for like-for-like comparisons







Summary

- Fuel rod operates at prototypic PWR conditions to specified burnup
  - Generates appropriate fuel pellet equilibrium conditions prior to transient
- Fuel temperatures profile flattens during the initial LOCA phase
  - Characteristic time for heat removal is 5-7 seconds
  - Variation expected in blowdown heat removal characteristics
  - Removing the temperature gradient generates fuel stresses
- Primary dependencies for FFRD identified by fuel performance analyses
  - Pre-transient power, heating rate, terminal temperature, and cladding response
- TREAT and SATS LOCA designs can be developed to provide a range of complementary conditions to investigate FFRD under LOCA conditions

Question?